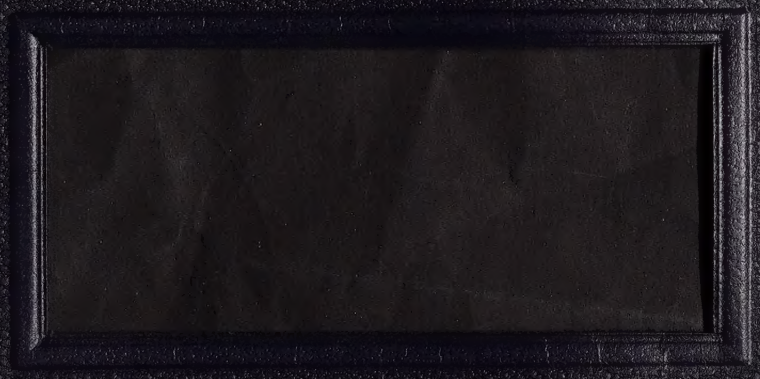

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INSTRUCTION MANUAL

MODEL JB-4

LOCK-IN AMPLIFIER

SERIAL NUMBER 286

LOCK-IN AMPLIFIER

MODEL JB-4

INSTRUCTION MANUAL

PRINCETON APPLIED RESEARCH CORPORATION
POST OFFICE BOX 565
PRINCETON, NEW JERSEY

O.K.

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I. SPECIFICATIONS

GENERAL:

FREQUENCY RANGE:

15 cps to 15,000 cps in three ranges. Calibration accuracy ± 5%.

GAIN: (RMS AC in to push-pull DC out) Greater than 9,000.

NOISE REJECTION:

A signal 40 db below ambient white noise in a 1 kc band width centered about signal frequency may be recovered with signal to noise ratio of 1.

EQUIVALENT BAND WIDTH:

0.12 cps minimum (2 seconds maximum RC integrating time). 6 or 12 db per octave roll-off selectable by front panel switch.

HARMONIC REJECTION:

Second harmonic down by factor of 1000 or 60 db. Third harmonic down by factor of 200 or 46 db.

OUTPUT:

± 5 volts D.C. maximum balanced to ground in series with approximately 5 k or 10 k (depending on selected recorder output). Will drive any 1 milliamp full scale pen recorder with less than 2 k internal impedance such as Esterline Angus or Texas Instrument Recti/riter. Also direct reading panel meter.

POWER REQUIREMENTS:

105-125 volts or 210-250 volts; 50-60 cps.

SIGNAL CHANNEL CHARACTERISTICS:

INPUT IMPEDANCE:

Approximately 50 k.

INPUT LEVEL CONTROL:

Input signal may be attenuated up to a factor of 1000 in steps of .5, .2, .1, .05, .02, .01, .005, .002, .001; accuracy ± 5%.

FREQUENCY SELECTIVE AMPLIFIER:

Selectivity characteristic of tuned amplifier in signal channel is that of parallel resonant circuit with a Q of approximately 25.

REFERENCE CHANNEL CHARACTERISTICS:

The reference signal, by which the signal to be measured is demodulated, is

obtained by three modes of operation; INTERNAL, EXTERNAL AND EXTERNAL SELECT.

EXTERNAL SELECT MODE:

Externally generated reference signal filtered by tuned amplifier, having characteristics of parallel resonant circuit with a Q of approximately 25, phase shifted and applied directly to demodulator. Minimum of 100 millivolts peak to peak required.

EXTERNAL MODE:

Externally generated reference signal phase shifted and applied directly to demodulator. 5 volts peak to peak reference signal required.

INTERNAL MODE:

Self contained oscillator drives demodulator (through phase shifter) directly. Output frequency appears as sine waves at "REFERENCE IN/OUT" terminals. Maximum output 5 volts peak to peak.

OUTPUT:

LEVEL:

Maximum D.C. output
a) into high impedance load $\pm$ 5 volts
b) into pen recorder of less than 2 k resistance $\pm \frac{1}{2}$ milliamp or $\pm$ 1 milliamp (switch selectable)

COMMON MODE QUIESCENT VALUE:

-8 volts D.C.

MONITOR:

A five position switch allows the panel meter and monitor output terminals to be switched to SIGNAL, REFERENCE, OFF and two output points in the instrument OUT X1 and OUT X10 for level monitoring, setting up, zeroing, etc. The meter measures the peak to peak A.C. voltage when it is switched to REFERENCE and SIGNAL positions.

LINEARITY:

$\pm$ 1% of full scale.

ZERO DRIFT:

$\pm \frac{1}{2}$% of full scale/hour.

II. PRELIMINARY INSTRUCTIONS

COOLING: Because of the low total power consumption of the instrument its case is unventilated. When installing the instrument the only precaution to be observed is to insure that the ambient temperature in which it is operated will not exceed 45°C (113°F). This will insure trouble-free continuous operation of the instrument.

POWER REQUIREMENTS: The instrument requires approximately 10 watts at either 105 to 125 V. A.C. or 210 to 250 V. A.C.; 50 to 60 cycles. The instrument is normally shipped wired for 105 to 125 V. operation. If the instrument is shipped wired for 210 to 250 V. operation, the line cord will bear a tag at the plug end attesting to this fact. Transformer primary connections for changing from 117 V. A.C. to 234 V. A.C. or vice versa are illustrated in Fig. 1 and the procedure for making this change is outlined below.

1. Remove the top, bottom and back sheet metal covers from the instrument (Each of these is held by 6 screws).

2. Remove the right (viewed from the front) side panel by removing the 4 screws securing it to the printed circuit board assembly, and the 2 screws securing it to the front panel. Easy access to the power transformer may now be had from the right side of the instrument.

3. The transformer primary connections for 117 V. A.C. operation are shown in FIG. 1A.

4. The transformer primary connections for 234 V. A.C. operation are shown in FIG. 1B. The instrument case can be reassembled by reversing the above procedure.

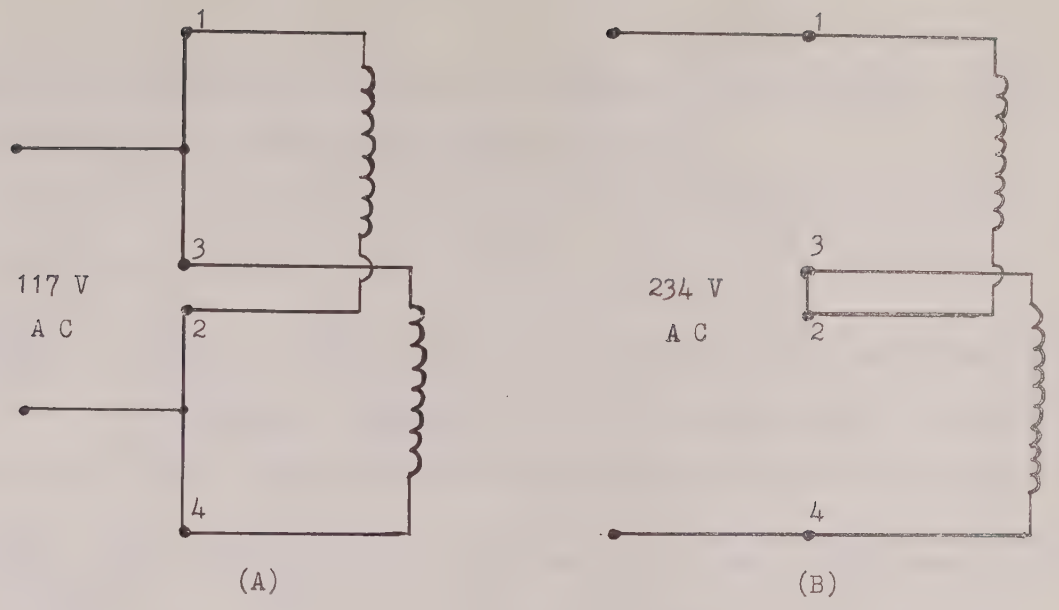


FIG. 1

TRANSFORMER PRIMARY CONNECTIONS FOR OPERATION FROM EITHER 117 V A.C. OR 234 V A.C.

FUSING: A ¼ A. slo-blo 3AG 250 V. fuse is supplied, and gives adequate protection to the instrument in either 105 to 125 V. operation or in 210 to 250 V. operation at either 50 or 60 cps.

FRONT PANEL CONTROLS AND CONNECTIONS

POWER: In the "OFF" position this switch completely disconnects the power line from the instrument.

SIGNAL LEVEL: This control sets the fraction of the voltage applied to the "SIGNAL INPUT" terminals which is applied to the input of the signal channel tuned amplifier.

SIGNAL INPUT: These terminals are connected to the input of the signal channel tuned amplifier via the "SIGNAL LEVEL" control. This input is single ended. The red binding post is the "high" side; the black binding post is connected to chassis

ground. A resistance of 54 K ± 5% (the resistance of the signal level control) is internally connected directly across these terminals.

CAUTION: THE VOLTAGE (D.C. + PEAK A.C.) APPLIED BETWEEN THESE TERMINALS SHOULD NEVER EXCEED ± 25 V.

FREQUENCY: This dial simultaneously tunes the reference and signal channel tuned amplifiers. The reference frequency in cps is the reading on the dial times the reading on the "FREQ. RANGE" switch. The accuracy of this frequency setting is ± 5%.

FREQUENCY RANGE: This switch selects the range which can be continuously tuned by the "FREQUENCY" dial. In the "X1" position this range is 15 cps to 150 cps; in the "X10" position, 150 cps to 1.5 Kc and in the "X100" position, 1.5 Kc to 15 Kc. This setting applies to both signal and reference channels.

FREQUENCY TRIM: This control varies the frequency of the signal channel tuned amplifier only. Total variation is approximately ± 5%. It is used to peak the signal channel at any given frequency setting, thus compensating for possible errors in tracking between the signal and reference tuned amplifiers.

PHASE: This control varies the phase of the reference relative to the signal. It provides a continuously variable shift of at least 180° at any frequency within the range of the instrument.

REFERENCE MODE: This switch is used to select one of the three reference modes of operation. (See "OPERATING INSTRUCTIONS" for a detailed description of the three possible modes of operation).

REFERENCE LEVEL: In either of the two external reference modes this control sets that fraction of the signal applied to the "REFERENCE IN/OUT" terminals which is applied to: (a) the input of the reference channel tuned amplifier, in

the "SEL. EXT." mode; and (b) the input of the phase shifter in the "EXT." mode. In the "INT." mode it controls the level of the sinusoidal output voltage appearing at the "REFERENCE IN/OUT" terminals.

REFERENCE IN/OUT: In the "EXT." reference mode these terminals connect to the input of the phase shifter via the "REFERENCE LEVEL" control. In the "SEL.EXT." mode these terminals connect to the input of the reference channel tuned amplifier via the "REFERENCE LEVEL" control. In either case the red binding post is the "high" side of the single-ended input, the black binding post being connected to chassis ground. A resistance of 54 K (± 5%) (the resistance of the "REFERENCE LEVEL" control) is connected directly across these terminals.

In the "INT." reference mode a sine wave signal at the reference frequency appears at these terminals. Its amplitude is set by the "REFERENCE LEVEL" switch. With this switch in the "1" position the sine wave output is approximately 5 V. peak to peak. In any other position the output is the fraction of this value indicated by the "REFERENCE LEVEL" control. The output from these terminals is single-ended, the red binding post being the "high" side and the black binding post being chassis ground. The impedance seen looking into these terminals varies with the "REFERENCE LEVEL" setting. It has a maximum value of approximately 1.4 K when this switch is in the "0.5" position.

FILTER: This switch determines the time constant of the RC low-pass filter at the output of the mixer. The numbers at each switch position give this time constant in seconds. In the "ZERO" position there is no internal low pass filtering at all.

6 DB - 12 DB PER OCTAVE SWITCH: This switch sets the roll-off rate of the RC low pass filter at the mixer output to either "6 DB/OCTAVE" (single RC filtering)

or "12 DB/OCTAVE" (double RC filtering). In either case the time constant of the filtering is as set on the "FILTER" switch.

OUTPUT: This group of 3 terminal is provided to drive a galvanometric recorder having a 0-1 mA movement and an internal resistance of less than 2K. When the panel meter (with the "METER/MONITOR" switch in "OUT X1" or "OUT X10" position) reads zero, the two red binding posts are at the same potential and are both at approximately -8V relative to chassis ground. The impedance seen looking into these two terminals is approximately $\binom{5K}{10K}$ when switch is in $\binom{1mA}{\frac{1}{2}mA}$ position. The black binding post is chassis ground.

INVERT: This switch inverts the phase (i.e. produces a 180° phase change) of the reference. It has the effect of inverting the sense of the mixer output voltage.

ZERO: This control sets the quiescent D.C. level of the output. It may be used to set the quiescent reading of the panel meter and (if used) to set the pen recorder to zero with no input applied to the instrument.

METER/MONITOR SWITCH: This switch performs two functions. It determines the internal point in the instrument monitored by the panel meter and simultaneously connects the same point to the "MONITOR" terminals for oscilloscope monitoring.

1. Panel meter: In the "SIG." position of the "METER/MONITOR" switch the meter indicates the output level of the signal channel tuned amplifier. In the "REF." position it indicates the output level of the phase-shifter. In the "OFF" position the panel meter is completely disconnected. In the "OUT X1" position the panel meter reads the output of the D.C. amplifier following themixer, full scale being 5 V. D.C. In the "OUT X10" position the panel meter reads the output of the D.C. amplifier, full scale in this case being 0.5 V. D.C.

2. Monitor terminals. In the "SIG." position of the "METER/MONITOR" switch the output of the signal channel tuned amplifier is available at these terminals. In the "REF" position the output of the phase-shifter appears at these terminals. In the "OFF", "OUT X1" and "OUT X10" positions the output of the D.C. amplifier appears at these terminals.

Notes: 1) The function of the "OUTPUT" terminals is uneffected by this switch.

2) It is undesirable to operate the instrument with the "METER/MONITOR" switch in the "SIG." or "REF." positions as the loading due to the meter circuit produces unbalances in the amplifiers being monitored.

MONITOR TERMINALS: This group of 3 terminals provide for oscilloscope monitoring of all important internal wave forms and also provides a low-impedance voltage output from the instrument in cases where such is desired. The waveform appearing at these terminals depends on the setting of the "METER/MONITOR" switch.

1. "SIG." position: In this case the two red binding posts are connected to the two outputs (push-pull) of the signal channel tuned amplifier. The upper one is at a D.C. level of approximately - 5 V. and the lower at approximately -1' V., relative to chassis ground.

2. "REF." position: In this position the upper red binding post is connected to the output (single-ended) of the phase-shifter. The lower one is connected to chassis ground. The upper terminal will be at a DC level of approximately -5V or -19V relative to chassis ground depending on the "INVERT" switch position.

3. In the "OFF", "OUT X1" and "OUT X10" positions of the "METER/MONITOR" switch the two red binding posts are connected to opposite ends of the output (push-pull) of the DC amplifier following the mixer. When the panel meter reads zero (in "OUT X1" or "OUT X10" positions) the voltage between these binding posts is zero. In this case both binding posts are at approximately -8 V. relative to

chassis ground. When the D.C. amplifier is delivering maximum output the D.C. voltage appearing between these terminals is $\pm$ 5 V (corresponds to $\pm$ full scale reading on panel meter with "METER/MONITOR" switch in "OUT X1" position). The voltage appearing between these terminals is the same in any of the last three ("OFF", "OUT X1" or "OUT X10") positions of the "METER/MONITOR" switch.

The black binding post is connected to chassis ground in any position of the "METER/MONITOR" switch.

III. OPERATING INSTRUCTIONS

GENERAL: The PAR Model JB-4 Lock-In Amplifier is essentially a detection system capable of operating with an extremely narrow equivalent noise band width. Its function is to select a band of frequencies from a signal spectrum applied to its input and to convert the information therein to an equivalent band width at D.C. The center frequency of the band so selected is equal to the reference frequency being used.

Figure 2 is a block diagram of the instrument. The signal containing the information to be detected is applied to the "SIGNAL INPUT" terminals. An appropriate fraction of this signal is picked off by the "SIGNAL LEVEL" control and applied to the input of the signal channel tuned amplifier. The role of this tuned amplifier is twofold:

1. By limiting the bandwidth at the detector input it increases the percentage of the peak input voltage to the detector which is due to the desired signal.

2. It attenuates components in the signal spectrum at the odd harmonics of the reference frequency to which the phase-sensitive detector is sensitive. (This sensitivity to odd harmonics of the reference frequency is due to the use of a square wave switching type phase sensitive detector).

The output of the signal channel tuned amplifier is applied to the input of the phase-sensitive detector. This is essentially a device which mixes the signal and reference frequencies so as to produce corresponding sum and difference frequencies at its output. A low-pass filter at the output of the phase detector rejects the high frequency components corresponding to sum frequencies, and passes those of the difference frequencies that lie within its pass-band. In particular the difference frequency due to components of the signal at the reference frequency is D.C. Components of the signal spectrum at frequencies differing from the reference frequency by more than the cut-off frequency of the low pass filter will produce difference frequencies which will be attenuated by it. Consequently the

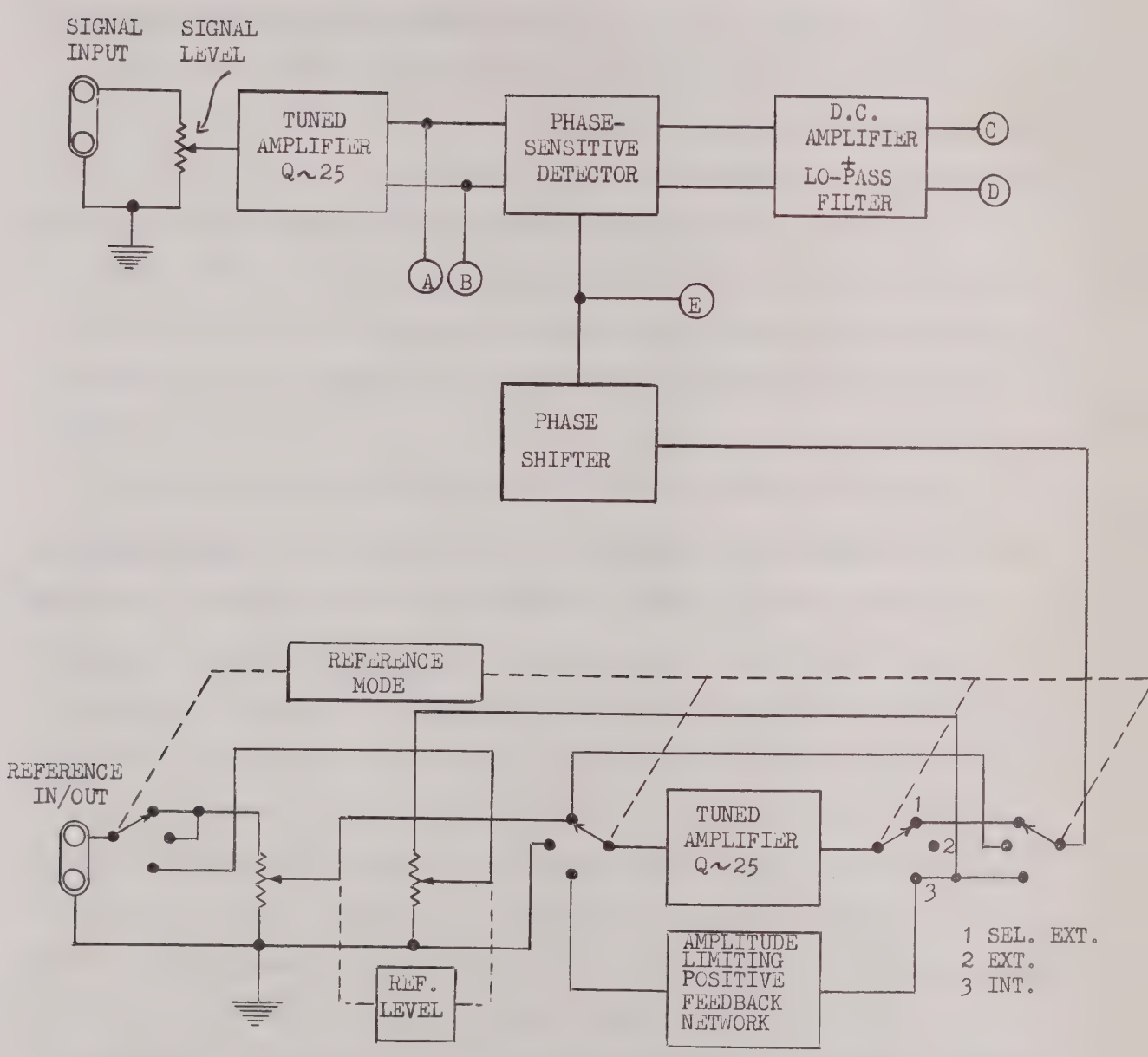


FIG. 2

BLOCK DIAGRAM MODEL JB-4 LOCK-IN AMPLIFIER

output from the low pass filter will be due to that portion of the signal spectrum which lies within a band of frequencies about the reference frequency determined by the pass band of the low pass filter.

The reason a mixer of this type is called a phase sensitive detector is that the D.C. output produced by it due to a signal at the reference frequency is proportional to the cosine of the relative phase of the signal and reference. This property is made explicit use of in some lock-in amplifier applications.

The reference frequency for this instrument may be generated internally or obtained from an external source. In either case a variable phase-shifter is available in order to allow the relative phase of the signal and reference to be adjusted as desired.

A detailed description of the operation of the instrument follows:

REFERENCE CHANNEL: The operation of the reference channel depends on the mode being used. Consequently the three available modes are treated separately.

EXTERNAL: This mode is used when a sine wave of at least 5V peak to peak is available for reference (at this level the mixer is insensitive to small changes in reference amplitude). If a reference waveform meeting these requirements is available it can be coupled into the instrument via the "REFERENCE IN/OUT" terminals located directly below the "REFERENCE LEVEL" control on the front panel. This input is single-ended, the red binding post being the "high" side and the black one being chassis ground. A resistance of 54K (± 5%) (the "REFERENCE LEVEL" control) is internally connected directly across these terminals (see FIG. 2). In this mode of operation the only adjustment required is to set the reference amplitude at the proper value. With the instrument power on and the reference source output connected to the "REFERENCE IN/OUT" terminals, set the "REFERENCE LEVEL" control at "OFF", the "REFERENCE MODE" switch to "EXT." and the "METER/

MONITOR" switch to "REF." Connect the input of an oscilloscope to the upper of the two red "MONITOR" terminals and the ground on the oscilloscope to the black terminal. Rotate the "REFERENCE LEVEL" control until the amplitude of the sine wave seen on the oscilloscope is between 4 and 6 volts peak to peak. Note the reading on the panel meter. This reading corresponds to a proper reference level for your instrument and may be used for checking and resetting (NOTE: a slight flattening of the positive peak of the sine wave may be observed. This is in no way harmful to the operation of the instrument).

The instrument is now set up for operation in the "EXT" reference mode.

SELECTIVE EXTERNAL MODE: In any reference mode the reference signal is passed through the phase-shift network before being applied to the detector. The detector is essentially a double-pole double-throw switch which is driven at the reference frequency. A square wave is required to drive the switch. This square wave is obtained by feeding the output of the phase shifter into a Schmitt trigger circuit. Certain non-sinusoidal waveforms applied to the input of the phase shifter will produce output wave forms which will produce improper triggering of the Schmitt and consequent improper operation of the detector. For this reason if the reference waveform is not sinusoidal it should be passed through the reference channel tuned amplifier in order to make it more nearly sinusoidal by reducing its harmonic content before applying it to the phase shifter. In general, this mode of operation allows a particular frequency component to be selected out of a complex waveform and used as the reference frequency.

With the instrument power on connect the output of the reference source to the "REFERENCE IN/OUT" terminals. This input is single-ended, the red binding post being the "high" side and the black one being chassis ground. A resistance of 54 K ($\pm$ 5%) is internally connected directly across these terminals (the "REFERENCE

LEVEL" control) (See FIG. 2). Set the "REFERENCE MODE" switch to "SEL.EXT.", the "REFERENCE LEVEL" control to "OFF", and the "METER/MONITOR" switch to "REF.". Set the "FREQ.RANGE" switch and "FREQUENCY" dial to the desired reference frequency. Connect the upper red "MONITOR" terminal to the input of an oscilloscope, and the oscilloscope ground to the black terminal.

Turn the "REFERENCE LEVEL" control clockwise until a sine-wave appears on the scope. Adjust the "FREQUENCY" control so as to maximize the amplitude of this sine wave. Adjust the "REFERENCE LEVEL" control so that the amplitude of the maximum response so obtained is 4 to 6 V. peak to peak as measured by the scope. (A slight flattening of the positive peaks of the sine wave may be observed; this in no way effects proper operation of the instrument).

If the desired frequency component of the reference wave form contributes only a small percentage of the peak amplitude of the waveform it may not be possible to obtain a sine wave of the amplitude specified above, due to the peak amplitude of the reference waveform exceeding the limits of the tuned amplifier. If this is the case the only solution is, by means of external filtering, to reduce the amplitude of the undesired frequencies in the reference waveform before applying it to the input of the tuned amplifier.

Once a sinusoidal waveform within the above amplitude limits has been obtained at the "MONITOR" terminals, note the reading of the panel meter. This reading corresponds to a proper reference level for your instrument and can be used for re-setting and checking.

The above adjustments having been carried out, the instrument is ready for operation in the "SEL.EXT." reference mode.

INTERNAL MODE: In general, operation in this mode requires no adjustments. However, in the case of a new instrument the operation in this mode should be

checked to make sure it is proper before the instrument is used. To do this, turn the instrument power on, set the "REFERENCE MODE" switch to "INT." and the "METER/MONITOR" switch to "REF." A reading should be observed on the panel meter of approximately 75% of full scale. Connect the upper red "MONITOR" terminal to the input of an oscilloscope; connect the scope ground to the black terminal. With the "FREQUENCY" dial set to 40 and the "FREQ. RANGE" switch to "X10" (i.e. 400 cps reference frequency) the amplitude of the sine wave appearing on the scope should be between 4 and 6 V. peak to peak (5 V. nominal). If this is not the case, refer to the internal oscillator section in "ALIGNMENT PROCEDURE" and follow the alignment instruction therein.

If the level observed on the scope is within the limits specified above the instrument is ready for use in the "INT." reference mode. Note the reading on the panel meter; this reading represents a proper reference level for your instrument. The level indicated by the meter will vary somewhat with frequency due to variation in the Q of the reference channel tuned amplifier with frequency. However, if adjusted as recommended at 400 cps this level will remain within acceptable limits over the entire frequency range of the instrument.

In this mode of operation a sinusoidal output is available at the "REFERENCE IN/OUT" terminals. This voltage has an amplitude of from 4 to 6 V. peak to peak and is controlled by the "REFERENCE LEVEL" control (this control does <u>not</u> effect the meter reading in the "REF." position, or the amplitude seen on the scope.) The impedance seen looking into the terminals under these conditions varies with the "REFERENCE LEVEL" setting, being a maximum of 1.4 K in the "0.5" position. This output is single-ended, the red binding post being the "high" side and the black one being chassis ground.

<u>SIGNAL CHANNEL</u>: The "SIGNAL INPUT" binding posts are located directly below

the "SIGNAL LEVEL" control on the left side of the panel. This input is single-ended, the red binding post being the "high" side and the black binding post at chassis ground (see note).

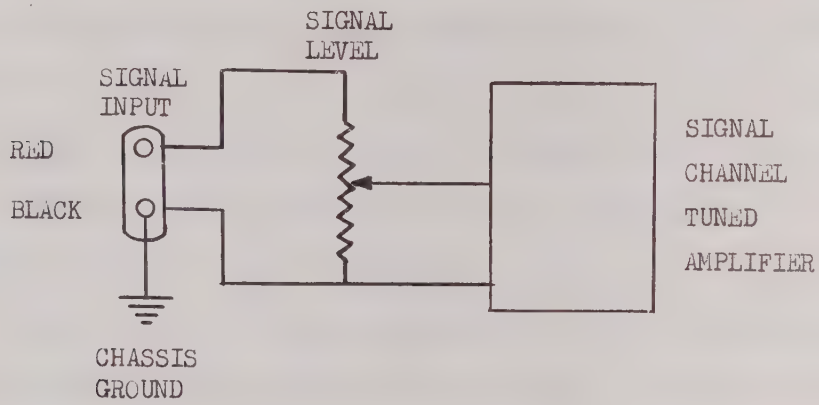


FIG. 3

NOTE:

When dealing with low level signals it is important to avoid injecting spurious voltages into the "SIGNAL INPUT" due to ground currents. In general, the best arrangement is to have only one ground connection between the signal source and the lock-in amplifier and to make this connection to the black "SIGNAL INPUT" binding post. In cases where large ground currents flow between the lock-in amplifier chassis and the signal source, other arrangements may be better; the best one in a given situation can only be determined by trial and error.

A 54 K (± 5%) resistor (the "SIGNAL LEVEL" control) is internally connected directly across these terminals (see FIG. 2).

It is assumed here that the reference channel is set up and operating in the desired mode and at the correct frequency (see "REFERENCE CHANNEL" section above). Connect the output of the signal source to the signal terminals and with the reference channel operating, set the "SIGNAL LEVEL" switch to "OFF" and the "METER/MONITOR" switch to "SIG." Adjust the signal source so that it is producing a signal of the desired frequency and phase. Turn the "SIGNAL-LEVEL" control clockwise until a reading is obtained on the panel meter. Adjust the "FREQ. TRIM" control so as to maximize this reading. Set "SIGNAL-LEVEL" control so as to obtain about 1/2 scale reading with the "FREQ. TRIM" so adjusted. Advance the "SIGNAL-LEVEL" control one position clock-wise. The meter should deflect to at least full scale; if it does not it means the total signal level is high enough to drive the signal channel tuned amplifier near the end of its linear range. In such a case it is necessary either to:

1. Use a lower setting of the "SIGNAL LEVEL" control with subsequent loss of sensitivity.

2. Reduce the level of the spurious components accompanying the signal by means of external filtering before applying the signal to the input terminals of the lock-in amplifier. Once a satisfactory adjustment is obtained as outlined above, a final oscilloscope check is desirable. With the "METER/MONITOR" switch in the "SIG." position, the output of the signal channel tuned amplifier (points A and B in Figure 2) is available at the "MONITOR" terminals. A single-ended scope input may be connected between either red terminal and the black ground

terminal. If desired a balanced input scope may be connected between the two red terminals. The waveform seen should be sinusoidal and free of any flattening or clipping on peaks. If such flattening is observed, the level in the tuned amplifier is too high and one of the two alternative procedures listed above should be followed to correct the situation.

This completes the preliminary adjustment of the signal channel.

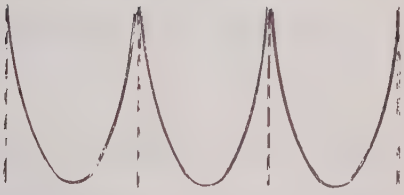
PHASE SHIFTER: With the signal and reference channels operating and adjusted as described above, place the "FILTER" switch in the "ZERO" position and the "METER/MONITOR" switch in the "OUT X1" position. Connect an oscilloscope to the "MONITOR" terminals. (These terminals are now connected to points C and D in FIG.2). A single-ended scope may be connected between either red terminal and the black ground terminal. A balanced scope input may be connected between the two red terminals. If the signal level has been set according to the above instructions a substantial deflection of the panel meter should be observed.

If the reading on the panel meter fluctuates wildly due to noise accompanying the input signal, turn the "FILTER" switch clockwise, thus narrowing the bandwidth until the fluctuations are reduced to an acceptable level. If "in phase" operation of the instrument is desired, rotate the "PHASE" control until maximum average deflection of the meter is obtained. If "90^{o} out of phase" operation is desired, adjust the "PHASE" control so that the average reading of the meter is zero. Oscilloscope waveforms corresponding to the two cases are shown in FIG. 4. These wave forms correspond to a pure sine wave signal; in a case where the signal is accompanied by noise they may be somewhat obscured by the noise but they should be still easily recognized. These waveforms can only be observed with the "FILTER" in the "ZERO" position. If this results in wild excursions of the meter, turn the "METER/MONITOR" switch to the "OFF" position while examing these wave forms.

A

B

C



D

FIG. 4

MIXER OUTPUT WAVEFORMS A AND C - SIGNAL AND REFERENCE 90° OUT OF PHASE - B AND D - SIGNAL AND REFERENCE IN PHASE. THE VERTICAL LINES REPRESENT MIXER SWITCHING TIMES.

FINAL ADJUSTMENT: The adjustment described above having been made, the instrument is essentially ready for operation. All that remains is to set the "FILTER" switch for the desired output bandwidth and to adjust the "SIGNAL LEVEL" control for the desired output level from the instrument. This being done, a final oscilloscope check of the waveforms at the output of the signal channel tuned amplifier and the mixer output is desirable in order to check for an overloaded condition at either point. Any evidence of peak-flattening at the former place means the signal level must be reduced (see "SIGNAL CHANNEL" section). If the occasional noise transient is being clipped by the mixer but the tuned amplifier is operating properly, the operation of the instrument will not be impaired. The transient response of the mixer is good enough to enable it to handle an occasional overload noise pulse. Evidence of severe mixer overload, however, means the signal

level must be reduced (again see "SIGNAL CHANNEL" section).

RECORDER OPERATION: If a galvanometer type recorder such as the Esterline Angus or Texas Instruments Recti/riter is to be used it should be connected to the two red "OUTPUT" binding posts. The lock-in amplifier will drive any such recorder of 0 - 1 ma sensitivity with a coil resistance of less than 2K.

Two modes of operation are provided for such recorders; "left hand zero" operation and "center zero" operation. A toggle switch located on the rear of the instrument selects the desired mode, and a screwdriver-adjust potentiometer, also located on the back of the instrument allows the recorder to be adjusted to agree with the panel meter.

LEFT-HAND ZERO OPERATION: In this mode of operation the recorder pen lies at the left-hand edge of the chart when the panel meter reads zero[1] and at the right-hand edge when the panel meter reads full scale[1]. If such operation is desired, the set-up is as follows: First set the recorder pen at the left-hand chart edge by means of the mechanical zero-adjuster on the recorder. Set the "METER/MONITOR" switch to the "OUT X1" position and connect the recorder to the two red "OUTPUT" terminals. Adjust the "ZERO" control on the instrument so that the panel meter reads zero. Put the toggle switch on the rear of the instrument in the "1 mA" position, (up). Apply an input signal to the instrument and adjust its amplitude so that the panel meter reads full scale. (If the recorder does not deflect in the same direction as the panel meter, reverse its connections at the "OUTPUT" terminal). Rotate the "F. S. ADJUST" pot (also on the rear of the instrument) until the recorder also reads full scale.

CENTER ZERO OPERATION: In this mode of operation the recorder pen lies at the center of the chart when the panel meter reads zero[1], and at the $\begin{pmatrix}\text{left}\\\text{right}\end{pmatrix}$ edge of the chart when the panel meter reads $\begin{pmatrix}-\\+\end{pmatrix}$ full scale[1]. If such operation is desired, set the recorder pen to the center of the chart by means of the mechanical zero-adjuster on the recorder. Set the toggle switch on the rear of the instrument to the "½ mA" position (down) and proceed as outlined in the preceding section.

[1] With the "METER/MONITOR" switch in the "OUT X1" position.

Operation with new Esterline-Angus rectilinear recorder: This recorder is 1 milliamps full scale with an internal resistance of about 6K. It may be used with the JB-4 but not quite as conveniently as the 1.5K type.

CENTER ZERO OPERATION: Follow the instructions for CENTER ZERO OPERATION on Page 19 with the exception that the rear panel toggle switch must be placed in the"1 mA" (up) position.

LEFT HAND ZERO OPERATION: Use the mechanical zero adjuster on the recorder to set the pen at the left hand edge of the chart at zero input. With the METER/MONITOR switch in the "OFF" or "OUT X1" position, plug the recorder into the two red MONITOR terminals. When the recorder reads full scale the JB-4 panel meter will read somewhat off-scale. (This will not damage the panel meter).

There is no way to make the panel meter track the recorder under these conditions except by changing the meter multiplier resistors internal to the Lock-In Amplifier.

ADDENDA

RECORDER OPERATION, SERVO TYPE: Recorders of this type are voltage rather than current measuring devices. Thus it is necessary to convert the current output of the JB-4 into a voltage output whose range is suited to the recorder being used. These recorders are available either with single-ended (one input terminal grounded) or push-pull (floating) inputs. The latter are somewhat more compatible with the JB-4.

PUSH-PULL INPUT TYPES: (See Figure A) When the JB-4 panel meter (in the "OUT X1" or "OUT X10" position of the METER/MONITOR switch) reads zero the two red OUTPUT terminals are at the same potential (-8V relative to chassis ground). A push-pull input recorder used with the JB-4 thus must be able to stand an 8 V common-mode level at its input terminals (see recorder instruction manual). If this voltage (8V) exceeds the common-mode rating of the recorder it would be best to ground one of its input terminals and treat it as a single-ended recorder (see following

section). If the recorder has this degree of common-mode rejection, proceed as follows. Connect a resistor (preferably wirewound) across the input terminals of the recorder whose resistance R, in ohms is given by:

$$10^{-3} R = E_{F.S.}$$

where $E_{F.S.}$ is the voltage required at the input to the recorder to obtain a full-scale deflection of the pen. This converts the recorder into a 1 milliamp full-scale instrument. If the recorder is now connected to the OUTPUT terminals of the JB-4 the set-up instructions given in the preceding section for galvanometer-type recorders may be followed exactly.

SINGLE-ENDED INPUT TYPES: In most cases it will be possible to simply "float" the recorder on the JB-4 output. To do this connect the ground terminal of the recorder to one of the JB-4 OUTPUT terminals, and the recorder input terminal to the other. THERE MUST BE NO CONNECTION BETWEEN THE RECORDER CHASSIS AND THE JB-4 CHASSIS. If the recorder has a 3 wire line cord an isolating adapter must be used. With some recorders using 60 cycle choppers, trouble may be encountered under these conditions due to 60 cycle pickup. Usually this can be cured by connecting a one microfarad or larger capacitor between the JB-4 chassis and the recorder chassis. (If an electrolytic capacitor is used, observe polarity; recorder chassis is at -8V relative to JB-4 chassis). If this fails to clear up the trouble (also try reversing recorder line plug in socket), then the procedure outlined below must be used.

If however all seems well, connect a resistor whose value is obtained from the equation in the preceding section across the recorder input terminals and proceed as described in that section.

Should "floating" operation not be possible then the following technique must be employed (See Figure A).

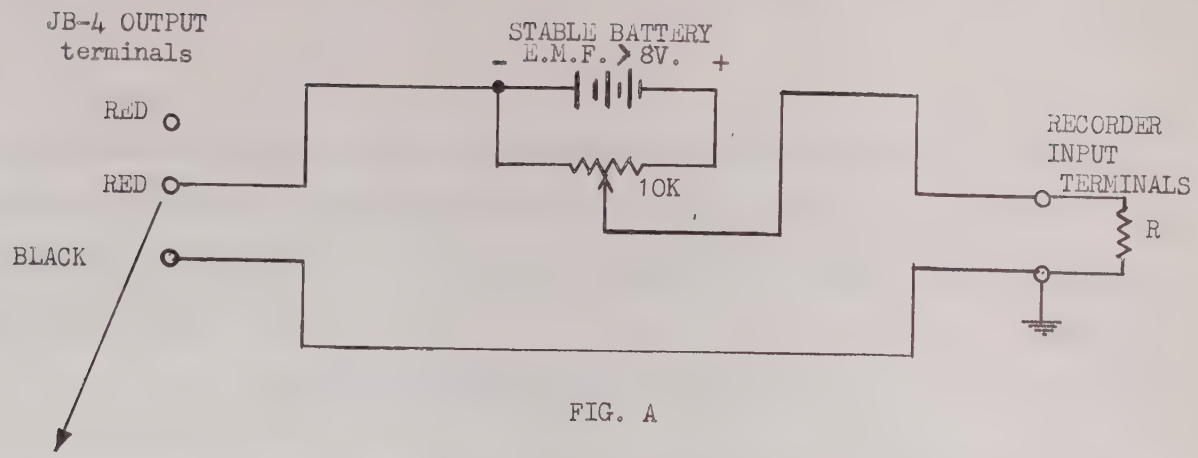


FIG. A

Use lower red output terminal. In this case 1mA/1/2mA switch will not affect recorder operation.

The 10K potentiometer is adjusted until the JB-4 panel meter indicates zero when the recorder also indicates zero. (Left-hand, right-hand or center zero may be used for recorder). R is then adjusted so that when the JB-4 panel meter reads full scale, the recorder indicates full scale also. The value of R for center zero operation will be different (about 1/2) from that required for left or right hand zero operation. It is recommended that mercury cells be used to establish the 8V "bucking potential".

Some single-ended recorders have considerable "zero suppression" built in. This is usually expressed as a multiple of full scale, i.e. 10 X full scale. If sufficient zero suppression is available the somewhat simpler arrangement shown below can be used (Fig. B).

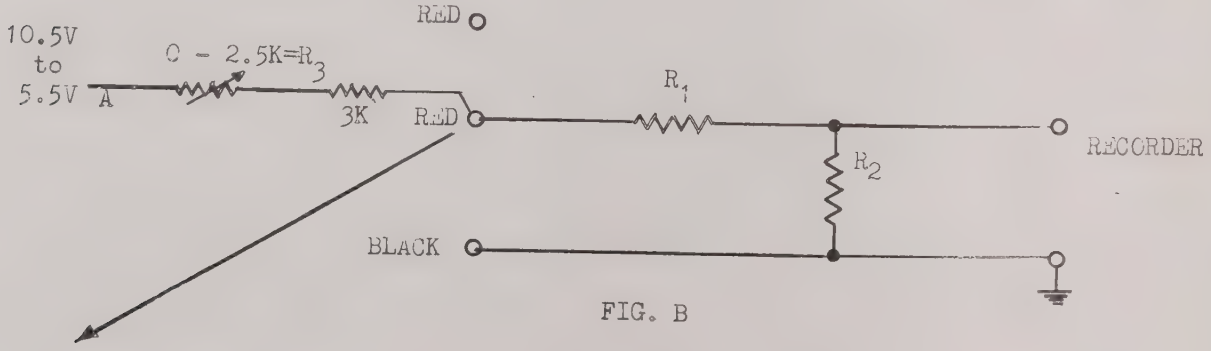


FIG. B

N.B. Use lower red terminal.

Let $E_{Z.S.}$ be the maximum recorder zero suppression and $E_{F.S.}$ be the recorder full scale voltage. A voltage divider, consisting of R1, R2 and the 3K and 2.5K

resistors inside the JB-4 is set up at the JB-4 output. Since the D.C. level at the point A in FIG.B is -8V when the JB-4 panel meter indicates zero, if the resulting D.C. level at the recorder is to be within its range of zero suppression then we must have:

$$8 \times \frac{R_2}{R_3 + 3K + R_1 + R_2} = 8k \leq E_{Z.S.} \qquad (k = \text{constant})$$

If full scale on the panel meter is to correspond to full scale on the recorder we must have:

$$2.5k = E_{F.S.}$$

i.e.

$$k = \frac{E_{F.S.}}{2.5}$$

and hence:

$$\frac{8}{2.5} = \frac{E_{Z.S.}}{E_{F.S.}}$$

that is if the zero suppression built into the recorder is $8 \div 2.5 = 3.2$ times full scale or better, it can be used in this way. R_3 which is the RECORDER ADJUST potentiometer located on the back of the JB-4 may be used for fine adjustment of full scale.

USE OF THE JB-4 TO DETECT SIGNALS AT HARMONICS OF SOME BASIC REFERENCE FREQUENCY.

In some Lock-In Amplifier applications the signal appears at a harmonic of the basic reference frequency. In such a case the Lock-In Amplifier must be operated at this harmonic frequency. The JB-4 is ideally suited to this sort of operation due to its continuously tunable reference channel tuned amplifier. In general what one does is to feed the reference signal (assumed to be sinusoidal) into a simple harmonic generator and then pick off the desired harmonic by means of the tuned amplifier.

If even (2nd and higher) harmonics are of interest the following harmonic generator is useful:

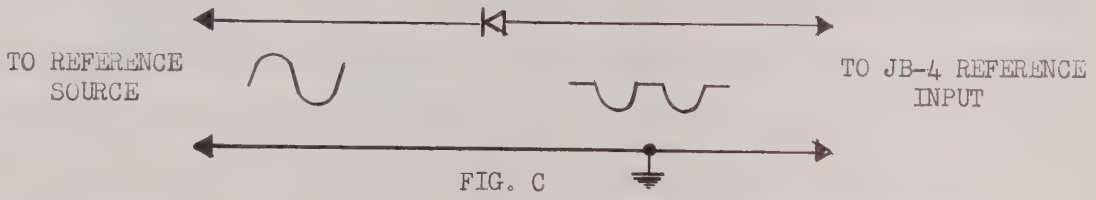


FIG. C

The amplitude of the reference sine wave should be several volts peak to obtain efficient rectification.

The Fourier Series of an ideal waveform of this type is:

$$E(t) = E_o \left[\frac{1}{\pi} + \frac{1}{2} \sin \omega t - \frac{2}{\pi} \sum_{k=2}^{\infty} \frac{\cos k\omega t}{k^2 - 1} \right] \qquad (k \text{ even})$$

where $E(t)$ is the output waveform of the half wave rectifier and E_o is the peak value of the input voltage. Apart from the fundamental, the output contains only even harmonics, the amplitude of the 2n th harmonic being:

$$A_{2n} = \frac{2}{\pi} E_o \frac{1}{4n^2 - 1}$$

and for the second harmonic $n = 1$ therefore $A_2 = \frac{2E_o}{3\pi}$

For operation in the SEL. EXT. mode a minimum level of 100 millivolts peak to peak is required at the reference input terminals,

i.e. we must have

$$A_2 \geq 100 \text{ mV.}$$

i.e. $$\frac{2E_o}{3} \geq 100 \text{ mV.}$$

$$E_o \geq \frac{100 \times 3\pi}{2} \approx 500 \text{ mV.}$$

Since this is below the minimum value for efficient rectification by a silicon diode it is clear that any peak reference voltage of a few volts peak to peak or more will be adequate to drive the JB-4.

For second harmonic operation, simply feed the reference signal to the JB-4 via a diode as shown in Fig. C. Set the JB-4 FREQUENCY dial and FREQUENCY RANGE switch to the second harmonic of the reference frequency and proceed as described in the SELECTIVE EXTERNAL MODE section of OPERATING INSTRUCTIONS in this manual.

Operation on even harmonics higher than the second is possible. The following considerations should be understood before such operation is attempted.

The reference channel tuned amplifier at full gain (X1) can withstand an input of at least 1 V peak to peak and still maintain its normal selectivity characteristics. In order to assure proper operation maximum instantaneous peak input voltage must be kept below this level.(Of course for settings of the REFERENCE LEVEL control other than X1 this limiting value is proportionately higher). If a high order harmonic is used the level of the harmonic of interest will be considerably lower than the maximum instantaneous peak input level (E_o). If we assign a maximum value of 1 to E_o then the peak value of the 2n th harmonic is:

$$A_{2n} = \frac{2}{\pi} \frac{1}{4n^2 - 1} \geq 50 \text{ mV}$$

This gives a maximum value for n of 2. i.e. This method will allow operation on even harmonics up to the 4th. For still higher even harmonics the following circuit can be used.

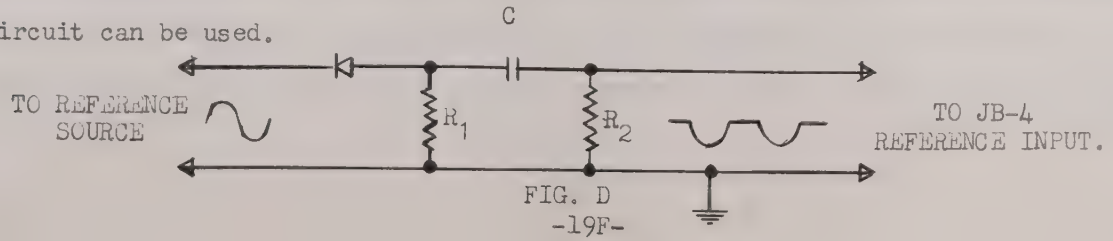


FIG. D

R_2 and C constitute a high-pass filter whose effect is to reduce the level of the lower order harmonics. A good choice for R_2C is a value such that

$$\omega_n = \frac{1}{R_2C}$$

where ω_n is the angular frequency of the desired harmonic. Of course more elaborate preselection methods may be used.

In any case the JB-4 is set to the frequency of the desired harmonic and set up as outlined in the SELECTIVE EXTERNAL section of OPERATING PROCEDURE in this manual.

If odd (3rd and higher) harmonic operation is desired the following circuit can be used (Fig. E).

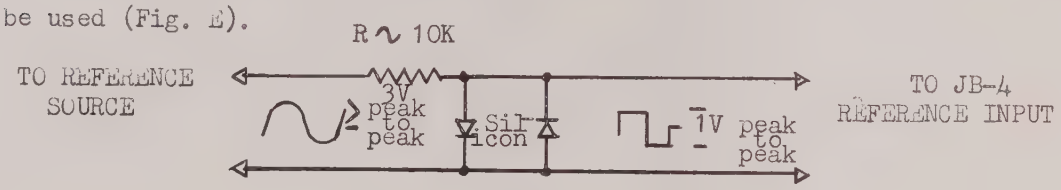


Fig. E

The resulting waveform has a harmonic structure given closely by:

$$E(t) = \frac{4E_0}{\pi} \sum_{k=0}^{\infty} (-1)^k \frac{\cos(2k+1)\omega t}{2k+1}$$

where E_0 is about 1/2 volt for silicon diodes. Using an argument similar to that of the preceding section it turns out that this arrangement will permit operation up to the 5th harmonic.

If operation at higher odd harmonics is desired the following circuit may be used.

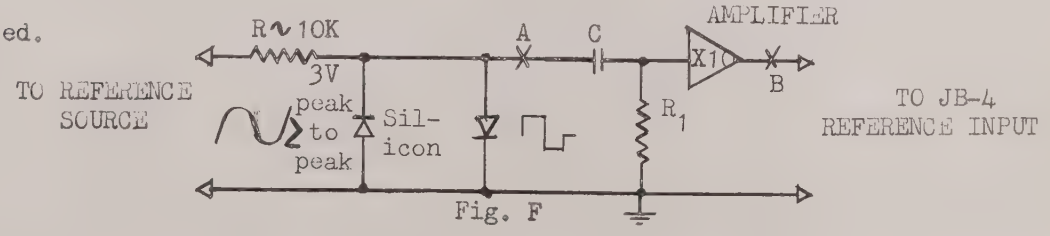


Fig. F

If $R_1C = \frac{1}{\omega_n}$ the voltage gain from A to B at a frequency ω_n will be approximately 7. At frequencies ω, below ω_n the gain is roughly proportional to ω. The amplitude of the harmonics in the input waveform however is proportional to $\frac{1}{\omega}$.

Therefore up to ω_n the various odd harmonics appearing at B are all about the same amplitude. If ω_n is chosen to be the highest harmonic of interest then operation at all odd harmonics below this will be possible.

In any case the JB-4 is tuned to the harmonic of interest and set up according to the procedure in the SELECTIVE EXTERNAL section of OPERATING INSTRUCTIONS in this manual.

IV. CIRCUIT DESCRIPTION

INTRODUCTION: The various circuit elements that go together to make up this instrument are assembled on five plug-in printed circuit boards. The distribution is as follows: (the identification nos. referred to appear on the printed wiring side of the boards).

Board No. TA 0209A SIGNAL CHANNEL TUNED AMPLIFIER.

Board No. TA 0209B REFERENCE CHANNEL TUNED AMPLIFIER.

Board No. PS 0112 PHASE SHIFTER AND A.C. VOLTMETER.

Board No. M 0113 MIXER AND D.C. AMPLIFIER.

Board No. P 0114 POWER SUPPLY.

Access to these boards may be had by removing the back panel of the instrument. They are located as shown in FIG. 5 which is a back view with the rear cover removed.

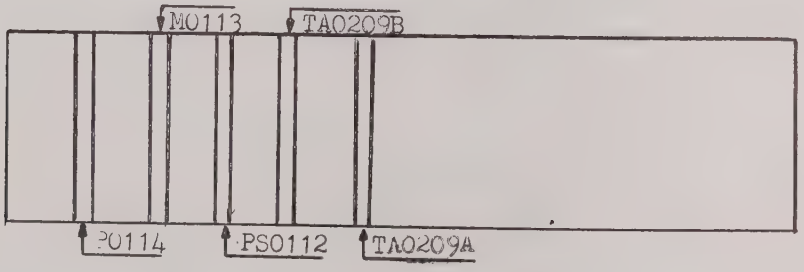


FIG. 5

The circuitry will be described board by board in order to assist those with the task of troubleshooting the unit and those users who wish to understand the principles of its operation.

PHASE SHIFTER (BOARD NO. PS 0112): The continuously variable phase-shifter used in this instrument is based on the following circuit:

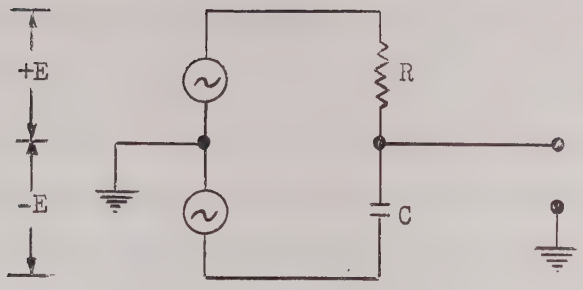


FIG. 6

A series RC combination is driven from a push-pull voltage source whose output is 2 E volts. The output is taken between the RC junction and ground as shown. Upon analysis of this circuit one obtains the result that the output voltage is E, independent of R, C and the angular driving frequency ω . The phase-angle, ϕ of the output voltage is given by:

$$\phi = 2 \text{ Tan}^{-1} \omega \text{ RC}$$

The phase-shifter employed in this instrument consists of a cascade of two such elements. The basic circuit of a single element is as shown in FIG.7.

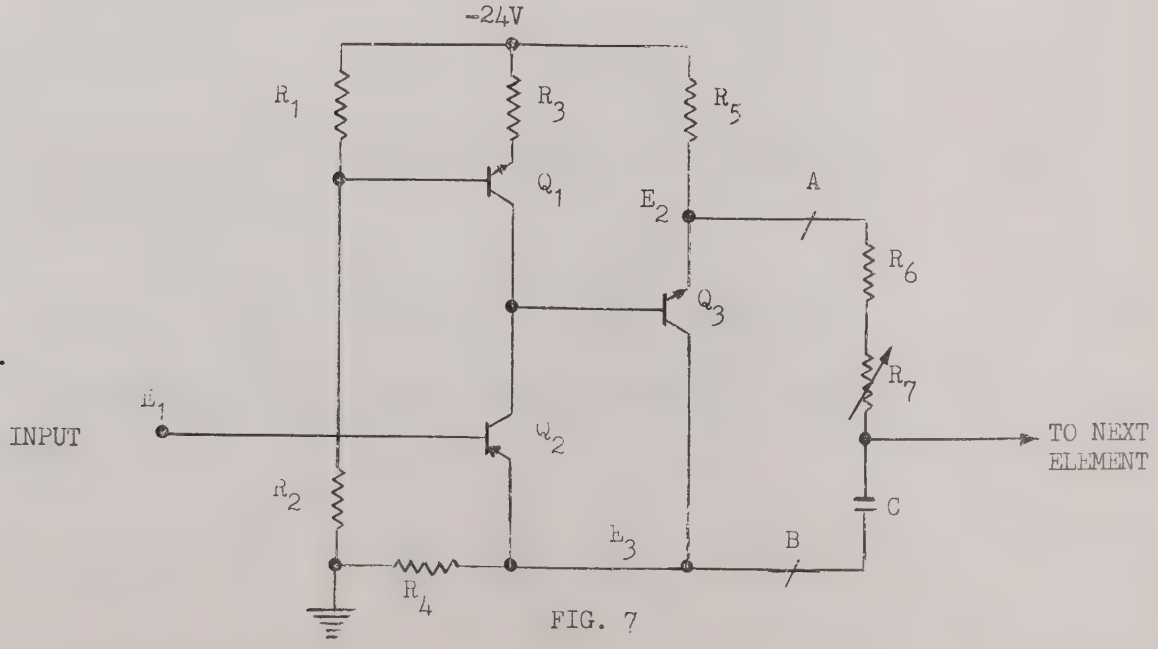


FIG. 7

Q_1 is a current source for the collector of Q_2, this current being set by the ratio R_1: R_2, and R_3. Because the collector of Q_1 represents a very high impedance compared to the base of Q_3, essentially all of the signal current generated in the collector circuit of Q_2 due to an input voltage E, flows into the base of Q_3. The resulting signal current in the emitter of Q_3 flows into R_5, that in the collector flows into R_4, (assuming for the moment that the load is disconnected at points A and B). If i_{c_3} is the signal collector current, and i_{e_3} the signal emmiter current in Q_3, then very nearly,

$$i_{c_3} \approx \alpha_3 i_{e_3}$$

where α_3 is the grounded base forward current transfer ratio of Q_3 and thus i_{R_5} the signal current in R_5 is given by:

$$i_{R_5} \approx \frac{1}{\alpha_3} i_{c_3}$$

The signal current flowing in R_4 is: $i_{c_3} + i_{e_2}$ where i_{e_2} is the signal emitter current of Q_2. Now we have:

$$i_{e_2} \approx + \frac{1}{\beta_3} i_{c_3}$$

where β_3 is the common emitter forward current transfer ratio of Q_3, i.e. the current in R_4 is:

$$i_{R_4} \approx i_{c_3} \left(1 + \frac{1}{\beta_3}\right) = \frac{1}{\alpha_3} i_{c_3}$$

Therefore, $i_{R_4} \approx i_{R_5}$ and the signal currents in R_4 and R_5 are very nearly equal. Thus:

$$\frac{E_2}{E_3} \approx \frac{R_4}{R_5}$$

and for $R_4 = R_5$ these voltages are equal in magnitude and opposite in phase. Since further, $\frac{E_1}{E_3} \approx 1$, this circuit is a unity-gain phase-splitter. The effect of connecting the phase-shift network (R_6, R_7 and C) at A and B is to place an impedance $\frac{Z}{2}$ (where Z is the impedance of R_6 and R_7 in series with C) in parallel with each of R_4 and R_5 and no unbalance is produced. Thus the conditions assumed in deriving the behavior of the phase-shift network are met by this circuit. Furthermore, because of the large amount of negative feedback employed in the phase-splitter these conditions are held closely over the range of frequencies and impedances (Z) encountered in the operation of the instrument.

Actual circuit values of the various components used are shown on the schematic diagram (0102-C-SD) for this board. The capacitors C are switched by the "FREQ. RANGE" switch. Their values are: in the "X1" position .47 mfd; in the "X10" position .047 mfd., and in the "X100" position .0047 mfd.

Q_{307} on the schematic functions as an output phase-splitter, giving two 180° out of phase outputs either of which is selected by the "INVERT" switch. A word of explanation on the role of C_{302} and R_{305} is in order.

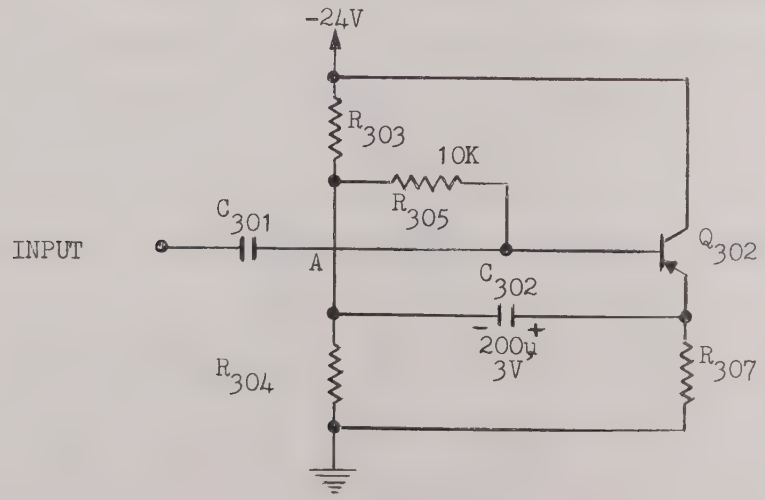


FIG. 8

C_{302} (see FIG. 8 and schematic 0102-C-SD) has the effect of making the signal voltage at the emitter of Q_{302} appear also at point A. If e_b is the signal voltage on the base of Q_{302} the voltage thus impressed on point A will be Ke_b where K is typically $\approx$ 0.98. Thus the voltage across R_{305} will be:

$$E_R \approx e_b - K e_b \approx 0.02\ e_b$$

i.e. the signal current flowing into R_{305} will be about 1/50 of what it would be without C_{305}. Thus it gives R_{305} an effective value $\approx$ 500K and greatly increases the A.C. impedance at the base of Q_{302}. This circuit is used elsewhere in the instrument to increase input impedances.

The component values in the phase-shifter elements themselves are chosen so that more than 180° of continuously variable phase shift is provided at any frequency within the range of the instrument. Thus, by making use of the "INVERT" switch any desired phase angle may be set between the signal and reference channels.

A. C. VOLTMETER/AMPLIFIER (BOARD NO. PS 0112): The input of the peak to peak voltmeter circuit is point V2 (see schematic diagram #0102-C-SD), its output being point W1. If a sine wave of E volts peak to peak swinging about any D.C. reference level is applied to V2, C_{305} will, due to the action of D_{301}, charge until the base voltage of Q_{312} swings as shown in FIG. 9A.

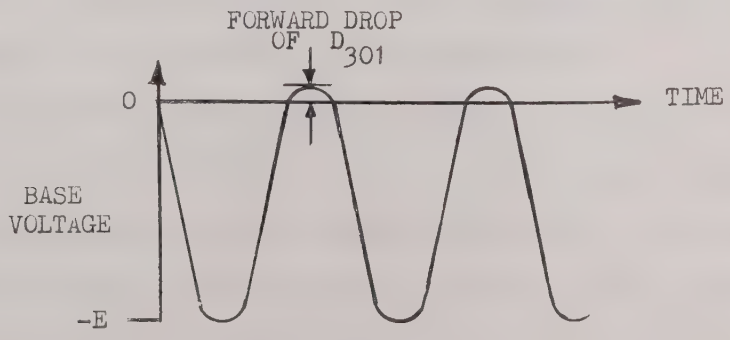


FIG. 9A

The voltage at the junction of D_{302} and R_{328}, R_{329} will be shown on FIG. 9B.

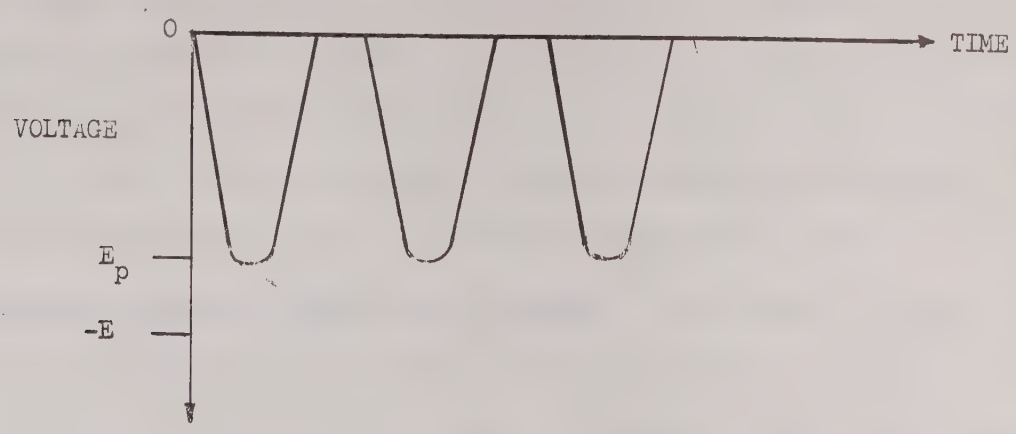


FIG. 9B

E_p will be given by:

$$E_p = E - (\text{forward drop } D_{301} + \text{forward drop } D_{302} + \text{base emitter drop } Q_{312}).$$

The D.C. average of this waveform will appear across C_{306}. This D.C. voltage is thus a function of the peak to peak voltage of the input waveform. This voltage is indicated by the panel meter in the "SIG." and "REF." positions of the "METER/MONITOR" switch.

In the "REF." position of the "METER/MONITOR" switch (see chassis wiring diagram #0148-C-SD) point V2 is connected to phase-shifter output voltage P_2. The A.C. voltage normally appearing at this point is about 5V. peak to peak. This voltage applied to V2 will produce, at W1, a D.C. voltage of about 1.5V as indicated by a meter with an impedance large compared to 18K.

In the "SIG." position of the "METER/MONITOR" switch (see chassis wiring diagram #0148-C-SD) point V2 is connected to the output of the meter amplifier (W2). The input to this amplifier is then connected to output O_2 (see signal channel tuned amplifier schematic diagram #0103-C-SD) of the signal channel tuned amplifier. Since the nominal level at this point is of the order of

30 M.V. peak to peak the amplifier is needed to bring the level of the input to the voltmeter circuit up to $\sim$ 3V. peak to peak. This amplifier uses the same circuit as that shown in FIG. 7 and the description accompanying FIG. 7 describes the operation of this amplifier as well. In this case however the ratio of the emitter resistors (R_{325}/R_{323}) is 100 instead of unity, and as a result this amplifier has (from V1 to W2) the required gain of 100.

TUNED AMPLIFIER (BOARD NOS. TA0209A AND TA0209B): (See schematic diagrams #0212-C-SD and 0213-C-SD). If one studies the aforementioned diagrams it will be evident that these two (reference channel and signal channel) tuned amplifiers are identical except for a few specific component values, and their nominal operating voltage. The different operating voltages are due to extra filtering and regulation being used on the voltage supply to the signal channel in order to reduce ripple in this supply voltage and to eliminate possible coupling to the reference channel via the power supply. Consequently this description will be made in terms of the reference channel unit, with the understanding that it applies to both.

The tuned amplifiers are based on the resonant transfer function of the following circuit:

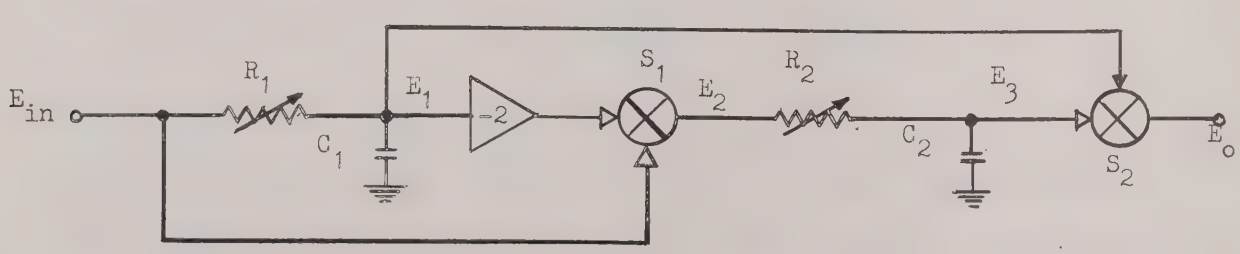


FIG. 10

$$\frac{E_1}{E_{in}} = \frac{1}{1 + j\omega R_1 C_1}$$

$$\frac{E_2}{E_{in}} = \frac{E_{in} - 2E_1}{E_{in}} = 1 - \frac{2}{1 + j\omega R_1 C_1} = \frac{-1 + j\omega R_1 C_1}{1 + j\omega R_1 C_1}$$

$$\frac{E_3}{E_{in}} = \frac{E_2}{E_{in}} \times \frac{1}{1 + j\omega R_2C_2} = \frac{-1 + j\omega R_1C_1}{(1 + j\omega R_1C_1)(1 + j\omega R_2C_2)}$$

$$\frac{E_o}{E_{in}} = \frac{E_3 + E_1}{E_{in}} = \frac{-1 + j\omega R_1C_1}{(1 + j\omega R_1C_1)(1 + j\omega R_2C_2)} + \frac{1 + j\omega R_2C_2}{(1 + j\omega R_1C_1)(1 + j\omega R_2C_2)}$$

$$= \frac{j\omega (R_1C_1 + R_2C_2)}{1 - \omega^2 R_1C_1R_2C_2 + j\omega(R_1C_1 + R_2C_2)} \quad \ldots\ldots 1$$

The normalized current in a series RLC resonant circuit is given by:

$$\frac{i}{i_o} = \frac{j \frac{\omega}{Q_o\omega_o}}{1 - (\frac{\omega}{\omega_o})^2 + j \frac{\omega}{\omega_o Q_o}}$$

where $\omega_o = \frac{1}{\sqrt{LC}}$ $\qquad Q_o = \frac{\omega_o L}{R}$ $\qquad i_o = \frac{E}{R}$

Equation 1 is of the same form as the equation for $\frac{i}{i_o}$ where: $\omega_o = \frac{1}{\sqrt{R_1C_1R_2C_2}}$

and $Q_o = \frac{\sqrt{R_1C_1R_2C_2}}{R_1C_1 + R_2C_2}$

If we define $R = \sqrt{R_1R_2}$ $\qquad C = \sqrt{C_1C_2}$ $\qquad$ and let $R_1 = aR$ $\qquad C_1 = bC$

$R_2 = R/a$ $\qquad C_2 = C/b$

Then $\omega_o = \frac{1}{RC}$; $\qquad Q_o = \frac{1}{ab + \frac{1}{ab}} = \frac{ab}{1 + (ab)^2}$

Note, however, that the transfer function is unity at resonance, independent of the values of a and b. In practice, the capacitors have nominally the same value with a tolerance of 5%, so b lies within $1 \pm .05$; tolerances (including tracking) on the R's are similar. The effect on Q_o is completely negligible: if $ab = 1 + \delta$, then

$$Q_o \approx \frac{1}{2}\left[1 - \frac{\delta^2}{2}\right]$$

and for $\delta \sim .1$, the Q_o differs from the maximum value by only 1/2%.

The actual circuit follows the block diagram of FIG. 10 closely except for a phase inversion right at the input and a liberal use of current sources in place of voltage sources (See Schematic Diagram 0212-C-SD). Let us take the base of Q_{203} as our input point. Any voltage E_{in} appearing there is transmitted to the base of Q_{205}, which then is a source of current

$$i_1 = - \frac{E_{in}}{R_{213}}$$

This current flowing in R_{214} produces a voltage

$$i_1 R_{214} = - E_{in} \frac{R_{214}}{R_{213}} \approx -E_{in}$$

with a source impedance equal to R_{214}; this resistor is thus a part of the frequency determining RC network. The voltage appearing at the base of Q_{209} is then the E_1 of the block diagram except for a sign change. This voltage is also applied (through the emitter followers Q_{209} and Q_{211}) to the base of Q_{204}, which provides the gain of -2. It also acts as the (current) summing junction S_1, accepting a current $- E_{in}/R_{210}$ from Q_{203}. The summed currents flowing in R_{215} produce (-) E_2, and the base of Q_{206} receives (-) E_3.

The two voltages which must finally be summed thus appear at the bases of Q_{206} and Q_{209}. To keep loading to a minimum, the impedances at these points must be as high as possible. This is accomplished by means of the additonal current gain provided by Q_{207} and Q_{208}; this sum current is equivalent to the output in the block diagram of FIG. 10.

Finally, the Q must be raised from 1/2 to the desired value of 25. This is accomplished by means of the following positive feedback network:

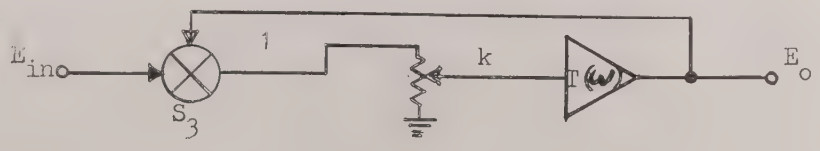


FIG. 11

The transfer function $T(\omega)$ is the one generated above:

$$T(\omega) = \frac{j\frac{\omega}{Q_o \omega_o}}{1-\left(\frac{\omega}{\omega_o}\right)^2 + j\frac{\omega}{Q_o \omega_o}}$$

Solving the loop equation, we find

$$K(\omega) = \frac{e_o}{e_{in}} = \frac{kT(\omega)}{1-kT(\omega)} = \frac{k\, j\frac{\omega}{Q_o\omega_o}}{1-\left(\frac{\omega}{\omega_o}\right)^2 + j\frac{\omega}{Q_o\omega_o} - k\, j\frac{\omega}{Q_o\omega_o}}$$

$$= \frac{k}{1-k} \quad \frac{j\frac{\omega}{\omega_o}\frac{1-k}{Q_o}}{1-\left(\frac{\omega}{\omega_o}\right)^2 + j\left(\frac{\omega}{\omega_o}\right)\frac{1-k}{Q_o}}$$

Thus $|K(\omega)|_{max} = k/(1-k)$; $Q_{eff} = \frac{Q_o}{1-k}$

To make $Q_{eff} = 25$, we need $1 - k = \frac{1}{50}$, or $k = .98$ and $K = 49 \approx 2\, Q_{eff}$

In the actual circuit, the input transistor, Q_{202}, operates in the same basic way as the input transistor in the phase shifter. The output current of this transistor is added to the output current of the frequency selective network at the emitter of Q_{201}, which thus serves as the summing junction S_3 of FIG. 11. The Q adjustment is then provided in R_{206}, which sets the k of FIG. 11.

Since the output of the frequency selective network does not appear as a voltage until it has already been added to the input at R_{206}, it is necessary to duplicate the summing junction S_2 (Fig. 10) for the final output. This is done by means of Q_{210} and Q_{211}, whose currents are summed at Q_{212} and sent to R_{223}. This signal then drives the split-load phase inverter Q_{213} which provides the push-pull output for the mixer.

If the behavior of the tuned amplifier is to duplicate the behavior of an RLC tuned circuit exactly it is necessary that the output of the tuned amplifier go to zero at frequencies far above and far below the resonant frequency. From FIG. 10 it is clear that since both E_1 and E_3 approach zero at high frequencies due to the action of C_1 and C_2, and since $E_o = E_1 + E_3$ there will be no output at these frequencies. At very low frequencies C_1 and C_2 may be neglected and

we have

$$E_1 = E_{in}$$

$$E_2 = E_{in} - 2E_{in} = -E_{in}$$

and $$E_3 = E_2 = -E_{in}$$

$$\therefore \quad E_1 = -E_3 = 0$$

and once again there is no output. This last case depends on the gain of the amplifier preceding S_1 being exactly -2. R_{211}, the LOW FREQUENCY BALANCE adjustment enables this gain to be so adjusted.

MIXER, D.C. AMPLIFIER (BOARD NO. M0113): Refer to schematic diagram (#0154-C-SD). The mixer proper consists of Q_{401} through Q_{406} and their associated components. The points marked α and β are driven 180° out of phase by a square wave at the reference frequency. They swing from approximately -9V to -7.5V relative to ground. Q_{403} and Q_{406} function as current sources, their collector currents being proportional to the instantaneous signal levels at M_1 and M_2. Assume for the moment that no signal is applied to M_1 and M_2. In this case the D.C. collector currents of Q_{403} and Q_{406} are determined by the bias string (R_{401}, R_{404}) and their respective emitter resistors. Consider what happens during the half-cycle when point α is at -9V and β is at -7.5V. The emitters of Q_{401} and Q_{405} will be held at about -8.7V, along with the emitter of Q_{402} and Q_{404}. Since the bases of Q_{402} and Q_{404} are thus at +1.2V relative to their emitters these transistors will be cut off. As a result, the collector current of Q_{403} will flow into R_{405} and that of Q_{406} will flow through R_{411}, the voltage drop across these resistors being determined by their respective currents. On the next half cycle the situation is reversed, Q_{403} feeding R_{411}, Q_{406} feeding R_{405}. In general the quiescent D. C. collector currents of Q_{403} and Q_{406} will not be the same and as a result the voltages across R_{405} and R_{411} will change each half cycle. The result will be a

reference frequency square wave at these two points. If R_{409} is adjusted to equalize these currents the square wave will disappear. If an A.C. input signal is now applied between M_1 and M_2 the resulting A.C. collector currents in Q_{403} and Q_{406} will be switched between R_{404} and R_{411} in just the way described above. Thus the mixer functions as a double-pole throw switch, being driven at the reference frequency. If a sine wave at the reference frequency and in phase with it is applied to the mixer input the output waveform will appear as shown in FIG. 11.

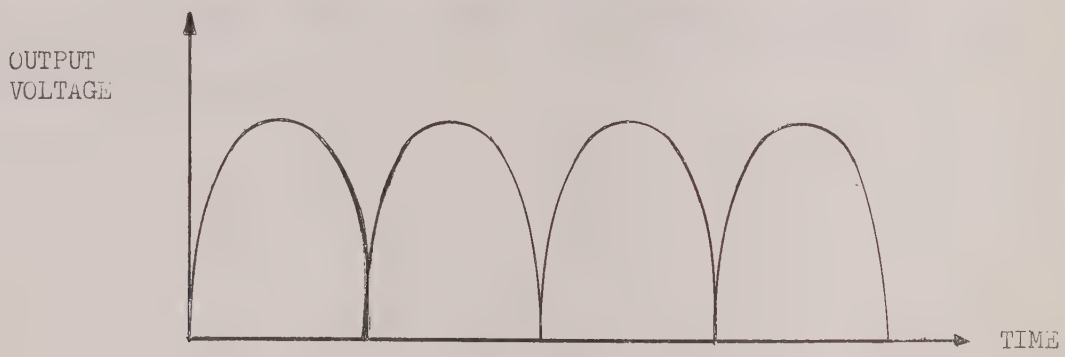


FIG. 11

The mixer is followed by a conventional balanced D.C. amplifier consisting of Q_{407} through Q_{413} and their associated components. (Components enclosed in dashed lines are not on the board; see chassis wiring diagram #0148-C-SD).

Q_{414} through Q_{416} and their associated components make up a Schmitt trigger circuit which generates the square wave to drive the mixer. Q_{417} is a driver for the Schmitt trigger circuit.

Except for the mixer the circuitry is conventional and no difficulty should be encountered in trouble-shooting by anyone versed in conventional transistor circuitry.

POWER SUPPLY (BOARD NO. P 0114): This board contains the -24V and -20V regulators. The circuits are completely conventional and require no detailed discussion. The output current (about 250 mA. in normal operation) is limited by D_{508} and R_{503} to about 500 mA under short circuit. If either supply is shorted, F_{501} will blow in about 1 minute. If trouble is encountered with the unit and F_{501} is found to be blown, locate the short circuit that caused it, correct it, and replace F_{501}.

NOTE: UNDER NO CIRCUMSTANCES USE A FUSE OTHER THAN THE TYPE SPECIFIED ON THE SCHEMATIC DIAGRAM AS A REPLACEMENT FOR F_{501}. IF AN EXCESSIVELY HIGH CURRENT FUSE WERE INSTALLED HERE A PROLONGED SHORT CIRCUIT COULD RESULT IN THE DESTRUCTION OF Q_{501}, Q_{508} OR BOTH.

V. ALIGNMENT PROCEDURE

INTRODUCTION: Removing the back cover from the instrument by removing the 6 screws that hold it in place gives access to all the alignment adjustment points except the oscillator level adjustment. The bottom panel must be removed for this adjustment.

SIGNAL CHANNEL TUNED AMPLIFIER: This board is on the extreme right viewed from the back of the instrument. It has two alignment Trimpots: "Q-ADJUST" being the lower one (R_{106}) and "LOW FREQUENCY BALANCE" the upper (R_{111}). In setting these up, the"LOW FREQUENCY BALANCE" should be set first as this adjustment affects the Q. The Q adjustment has very little effect on the "LOW FREQUENCY BALANCE."

LOW FREQUENCY BALANCE: This adjustment minimizes the response of the tuned amplifier to frequencies far from the resonant frequency. To adjust it, set the "METER/MONITOR" switch to "SIG.", the "SIGNAL LEVEL" switch to "1", and the "FREQUENCY" and "FREQ. RANGE" controls to give 15KC. Apply a signal of about 1 volt peak to peak at 15 to 60 cps to the signal input terminals. Adjust the "LOW FREQUENCY BALANCE" trimpot until the output seen at the monitor terminals by detector of millivolt sensitivity is a minimum.

Q ADJUST: This adjustment sets the Q of the tuned amplifier. To adjust it, set the "METER/MONITOR" switch to "SIG.", the "SIGNAL LEVEL" control to ".02", the "FREQUENCY" and "FREQUENCY RANGE" controls to a frequency of 400 cycles and apply a 400 cycle sine wave of about 50 mV. peak to peak to the signal input terminals. Connect a scope or A.C. voltmeter between either of the two red monitor terminals and ground and adjust either the frequency of the applied signal or the "FREQUENCY" dial on the lock-in amplifier for maximum output.

This having been done, vary the "Q ADJUST" control until the signal level at the "MONITOR" terminals is the same as that applied to the "SIGNAL INPUT" terminals. This sets the on-resonance gain of the tuned amplifier at 50 and since this gain is just 2Q it sets the Q at 25. The Q of both tuned amplifiers varies somewhat with frequency. A Q of 25 may be obtained at any frequency in the range by making the adjustment described above at that frequency. If a Q value different than 25 is desired, it may be obtained by setting the gain of the tuned-amplifier under these conditions to twice the desired Q value.

REFERENCE CHANNEL TUNED AMPLIFIER: This board is located second from the right as viewed from the back of the instrument. It has the same two adjustments as the signal channel tuned amplifier board, located in the same relative positions, and the adjustment procedure is the same as for the signal channel tuned amplifier board except for the differences noted below:

LOW FREQUENCY BALANCE: This adjustment is made in the same way as outlined for the signal channel except that the "METER/MONITOR" switch is set to the "REF." position, "REFERENCE MODE" switch to the "SEL. EXT." position and the input signal is applied to the "REFERENCE IN/OUT" terminals. "MONITOR" terminals in this case are single-ended; the lower red terminal is at chassis ground.

Q ADJUST: This adjustment is made in the same way as outlined for the signal channel except that the "METER/MONITOR" switch is placed in the "REF." position, the "REFERENCE MODE" switch in the "SEL. EXT." position, "REFERENCE LEVEL" control at ".02", and the input signal is applied to the "REFERENCE IN/OUT" terminals. The level of the input signal can be as much as 1V peak to peak. "MONITOR" terminals in this case are single-ended; the lower red terminal is at chassis ground.

PHASE SHIFTER A.C. VOLTMETER BOARD: This board is third from the right as viewed from the back of the instrument. There are no alignment adjustments on this board.

MIXER D.C. AMPLIFIER BOARD: This board is located second from the left as viewed from the back of the instrument. There are three adjustment trimpots on this board. The upper most one is the "SYMMETRY" adjustment (R_{437}), the middle one the "HYSTERESIS" adjustment (R_{427}) and the lower one the "A.C. BALANCE" adjustment (R_{409}). These should be adjusted in the order given below:

HYSTERESIS CONTROL: Turn the "SIGNAL LEVEL" control to "OFF", the "REFERENCE MODE" switch to the EXT." position, the "METER/MONITOR" switch to "OFF" and connect an oscilloscope between the junction of either R_{426} and R_{432} or R_{429} and R_{435} on the mixer board and ground. With the "REFERENCE LEVEL" control in the "1" position apply a sine wave of about 5 volts peak to peak to the "REFERENCE IN/OUT" terminals. Any convenient frequency between 15 cps and 15 KCS may be used. Under these conditions a square wave of about 1 volt peak to peak should be visible on the scope. Reduce the amplitude of the sine wave applied to the "REFERENCE IN/OUT" terminals until the Schmitt trigger just stops triggering. This is evidenced by the square wave disappearing from the scope. Increase the signal level until the Schmitt trigger circuit is just barely triggering. If the square wave is very asymmetrical under these circumstances, adjust the "SYMMETRY" control until it is reasonably symmetrical. Now again reduce the level of the input signal until the Schmitt trigger just stops triggering. By varying the "HYSTERESIS" control it should be possible to get the Schmitt trigger to trigger once more.

Keep reducing the signal level and readjusting the "HYSTERESIS" control until a point is reached at which the wave form of the square wave being produced by the Schmitt trigger begins to suffer. At this point it will begin to look more like a clipped sine wave. Back off somewhat from this point until a clean square wave is once more obtained. Readjust the "SYMMETRY" adjust control so that this square wave looks reasonably symmetrical.

SYMMETRY CONTROL: Before making this adjustment the "HYSTERESIS" control should be set as outlined in the preceding section. To make this adjustment two audio-oscillators are required. When the duty cycle of the mixer switching waveform is exactly 50% the response of the mixer to the second (and all other even harmonics) of the reference frequency is a minimum. The "SYMMETRY CONTROL" is provided to so adjust the switching waveform. Although this adjustment could be made by observing this waveform on a good scope and setting the duty cycle to 50% as indicated by the scope, the following procedure is much to be preferred since it serves to minimize the mixer's response to the second harmonic. Set the "METER/MONITOR" switch in the "REF." position, the "REFERENCE MODE" switch in "EXT." and connect one of the audio-oscillators to the "REFERENCE IN/OUT" terminals. Set the oscillator frequency at about 1KC and adjust the "REFERENCE LEVEL" control and/or the level control on the oscillator until the meter indicates a normal reference channel level. Set the "FREQUENCY" and "FREQ. RANGE" controls to a frequency of 1KC. Set the second oscillator to a frequency of 1KC and connect it to the "SIGNAL INPUT" terminals. Switch the "METER/MONITOR" switch to the "OUT X1" position and adjust the frequency of the second oscillator so that a slow beat is observed on the meter. Adjust the "FREQ. TRIM" control so that this beat has maximum amplitude. Now tune the oscillator connected to the "REFERENCE IN/OUT" terminals to about 500 cps. Set the "METER/MONITOR" switch on the "OUT X10" position and tune this oscillator slowly around 500 cps until a slow beat is observed on the meter. In general this beat will be of very small amplitude. Adjust the "SYMMETRY" control until the amplitude of the beat so observed is a minimum. This leads

to a proper adjustment of the "SYMMETRY" control.

A. C. BALANCE CONTROL: To set this control, set the "REFERENCE MODE" switch in the "INT." position, the "FREQUENCY" and "FREQ. RANGE" controls to a frequency of about 400 cps, the "SIGNAL LEVEL" control to "OFF", and the "METER/MONITOR" switch to the "OFF" position. Connect the scope between either of the red "MONITOR" terminals and ground. If a balanced scope is available, its use is to be preferred and it should be connected between the two red "MONITOR" terminals. Adjust the "A.C. BALANCE" control until the amplitude of the square wave seen on the scope is a minimum. This completes the adjustment of the "A.C. BALANCE" control.

POWER SUPPLY: This board is located on the extreme left as viewed from the back of the instrument. It has only one adjustment which is used to set the voltage on the -24 line at -24. This is R_{511} on the schematic diagram. In making this adjustment, it is necessary to remove the bottom panel from the instrument in order to gain access to the connector into which the power supply board is plugged. Connect an accurate D.C. voltmeter between pin 15 on this connector and the chassis. Pin 15 is the terminal on the connector closest to the bottom of the instrument. The meter should read 24 volts. If it does not, adjust R_{511} until the meter reads exactly 24 volts. Under these circumstances the voltage on pin 1 of the same connector should read -20 ± 2 volts. If the voltage read on pin 1 is outside of these limits, it indicates trouble in the 20 volt regulator which should be checked.

INTERNAL OSCILLATOR ADJUSTMENT: It is necessary to remove the bottom cover from the instrument in order to make this adjustment. The Trimpot involved

is mounted on the bottom edge of the printed circuit board which is mounted between the front panel and the panel carrying the connectors for the plug-in printed circuit boards. Before making this adjustment the Q of the reference amplifier should be set to 25. If this has not been done, this adjustment should be checked. See the section on the "REFERENCE CHANNEL TUNED AMPLIFIER" adjustment for instructions on doing this. The internal oscillator adjustment is made as follows: set the "REFERENCE MODE" switch on "INT.", the "REFERENCE LEVEL" control on "1" and the "FREQUENCY" and "FREQ. RANGE" dials to a frequency of 400 cps. Connect an oscilloscope across the "REFERENCE IN/OUT" terminals. A sine wave should appear on the scope. Adjust the "OSCILLATOR LEVEL" control until the amplitude of this sine wave is 5 volts peak to peak, as indicated by the scope. The "OSCILLATOR LEVEL" control is now properly set.

VI. WARRANTY

Princeton Applied Research Corporation warrants each instrument of its own manufacture to be free from defects in material and workmanship. Obligations under this Warranty are limited to replacing, repairing or giving credit for the purchase price, at our option, of any instrument returned prepaid to our factory for that purpose within ONE YEAR of delivery to the original purchaser. Instruments returned to the factory are accepted only when prior authorization has been given by an authorized representative of Princeton Applied Research Corporation.

This Warranty shall not apply to any instrument, which our inspection shall disclose to our satisfaction, to have become defective or unworkable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation, or other causes beyond our control. (Tubes, semiconductors, choppers, and lamp bulbs are exempted from this Warranty).

Princeton Applied Research Corporation reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This Warranty is in lieu of, and excludes all other warranties or representations, expressed, implied or statutory, and all other obligations or liabilities of Princeton Applied Research Corporation including special or consequential damages, and no other source is authorized to assume for Princeton Applied Research Corporation any other liability.

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